Chapter 5

MANAGING STORMWATER

Table of Contents

CHAPTER SECTION HEADINGS

FIGURES

TABLES

APPENDICES

5.0. INTRODUCTION: THE HISTORICAL REALITIES

The modern urban drainage system came into being soon after World War II. This generally consisted of a system of catch basins and pipes to prevent flooding and drainage problems by efficiently delivering runoff water to the nearest water body. However, as noted in **Chapter 4**, delivering the water too quickly often caused severe downstream flooding and streambank erosion in the receiving water. To prevent streambank erosion and provide more space for flood waters, some stream channels were enlarged and lined with concrete. While hardening and enlarging natural channels appeared to solve the erosion and flooding in the immediate vicinity, at some point the paved channels ended. The modified channels delivered increased peak flows to the unprotected receiving streams, often causing erosion and flooding further downstream and disturbing habitat necessary to support healthy aquatic ecosystems.

To control the quantity of water reaching the ends of pipes and channels during runoff events, on-site detention became the standard solution, requiring developers to reduce the peak flows of specified design storms. Detention can control peak flows directly below the point of discharge and at the property boundary. However, when designed on a site-by-site basis without taking other basins into account, they can lead to downstream flooding problems, because total flow volume is not reduced (McCuen, 1979; Ferguson, 1991; Traver and Chadderton, 1992; EPA, 2005d). In addition, in order to prevent clogging, openings in outlet structures for most basins are generally too large to hold back flows from smaller, more frequent storms – the storms that cause most of our water quality problems.

Because of the limitations of on-site detention, infiltration of urban runoff has become a recent goal of stormwater management, in order to control runoff volume. Without stormwater infiltration, Virginia communities can expect drops in local groundwater levels, declining stream base flows (Wang et al., 2003a), and flows diminished or stopped altogether from springs feeding wetlands and lakes (Leopold, 1968; Ferguson, 1994).

The need to provide volume control marked the beginning of Low Impact Development (LID) and Conservation Design (Prince George's County, 2000; Arendt, 1996), which were founded on the work of landscape architect Ian McHarg and associates decades earlier (McHarg and Sutton, 1975; McHarg and Steiner, 1998). The goal of LID is to allow for development of a site while maintaining as much of its natural hydrology as possible (e.g., infiltration, frequency and volume of discharges, and groundwater recharge). This is accomplished with infiltration practices, functional grading, open channels, disconnection of impervious areas, and the creation of less impervious surfaces. Much of the LID focus is to manage the stormwater as close as possible to its source – that is, on each individual lot rather, than conveying the runoff to a larger regional Best Management Practice (BMP). Individual practices include rain gardens, disconnected roof drains, permeable pavement, narrower streets, and grass swales. In some cases, LID site plans still must include a method for passing the larger storms safely from the site and through the downstream drainage system.

Evidence gathered in the 1970s and 1980s suggested that pollutants be added to the list of things in stormwater that need to be controlled (EPA, 1983). Damages caused by elevated flows, such as stream habitat destruction and floods, were relatively easy to document with something as simple as photographs. However, documentation of elevated concentrations of conventional and potentially toxic pollutants required intensive collection of water quality samples during runoff events. Early sampling efforts clearly showed the concentration of many pollutants, such as heavy metals and sediment, were elevated in urban runoff (Bannerman et al., 1979). Levels of heavy metals were especially high in industrial site runoff, and construction erosion was calculated to be a large source of sediment in watersheds. The National Urban Runoff Program added more evidence about the high levels of some pollutants found in urban runoff (Athayde et al., 1983; Bannerman et al., 1983).

With new development rapidly adding to the environmental impacts of existing urban areas, the need to develop effective stormwater management programs is more urgent than ever. Current day BMPs represent a radical departure from past practices, which focused on dealing with extreme flood events via large detention basins designed to reduce peak flows at the downstream property line. As described in this chapter, BMPs now include practices intended to meet broad watershed goals of protecting the biology and geomorphology of receiving waters in addition to flood peak protection. Effective stormwater management encompasses such diverse actions as using more conventional practices, like basins and wetlands, as well as installing stream buffers, reducing impervious surfaces, reducing runoff volume, removing pollutants, and educating the public.

5.1 TODAY'S STORMWATER MANAGEMENT GOALS

It is difficult to discuss methods of controlling stormwater without first considering the goals those methods are expected to meet. A broadly stated goal for stormwater management is as follows: *To reduce pollutant loads to water bodies and maintain, as much as is possible, the natural hydrology of a watershed.* This goal is translated more specifically in the Virginia Stormwater Management Law, as follows:

> ***. . . maintain after-development runoff rate of flow and characteristics that replicate, as nearly as practicable, the existing predevelopment runoff characteristics and site hydrology, or improve upon the contributing share of the existing predevelopment runoff characteristics and site hydrology if stream channel erosion or localized flooding is an existing predevelopment condition.*** (§ 62.1-44.15:28 A 7, Code of Virginia)

As is the case in numerous other states, Virginia relies on engineering criteria for BMP performance as the basis for more specific stormwater management goals. These criteria can be loosely categorized as:

Erosion and Sediment Control. This goal refers to the prevention of erosion and sedimentation from sites during construction and is focused at the site level. Criteria usually include a barrier plan to prevent sediment from leaving the site (e.g., silt fences, etc.), practices to minimize potential erosion of exposed soils (e.g., phased construction, timely stabilization, etc.), and facilities to capture and remove sediment from runoff (e.g., sediment basins, etc.). Because these measures are considered temporary, smaller storm events are designated as the design storms rather than those typically used if flood control is the goal.

Recharge Groundwater and Stream Base Flow. This goal focuses on sustaining the pre-construction hydrology of a site as it relates to stream base flow and groundwater recharge.

Water Quality Protection. This goal is usually crafted as a percent removal or a quantitative load limit for one or more specific target pollutants typically present in the stormwater discharge, and the goal is usually associated with a set volume ("Treatment Volume") of stormwater being treated by the BMPs. In Virginia, the target/indicator pollutant is Total Phosphorus.

Stream Channel Protection. This goal refers to protecting receiving stream channels from accelerated erosion during and immediately after storm events due to increased runoff. It is tied to the storm event that is presumed to be the typical "channel forming" storm event.

Frequent Flood Prevention. This goal addresses public safety and protection of property. It is applicable to storm events that exceed the carrying capacity of the receiving channel.

Extreme Flood Protection. This goal addresses public safety and protection of property in the event of an extreme or catastrophic storm event, such as the 100-year storm. In Virginia this goal addressed, as is typically done elsewhere, through flood plain management ordinances and BMP design criteria that provide for bypassing the extreme storm flow safely around stormwater control structures.

In Virginia, erosion and sediment control is the subject of a completely separate regulatory program. The other goals are discussed in more detail in **Chapter 10**, ***Unified Sizing Criteria***.

5.2 THE EMERGING SOLUTION

Some U.S. communities are already taking steps to successfully manage their land and develop using a more holistic, *green infrastructure* approach. Green infrastructure is our Commonwealth's life support system – an interconnected network of waterways, wetlands, woodlands, wildlife habitats and other natural areas such as greenways, parks and other conservation lands; working farms, ranches and forests; and wilderness and other open spaces. This green network supports native species, maintains natural ecological processes, sustains air and water resources, and contributes to the health and quality of life for Virginia's communities and citizens (adapted from Benedict and McMahon, 2006). More simply, green infrastructure is a network of ecologically significant blocks of landscape, called cores or hubs, which connect to linear bands of green space, called corridors.

Green infrastructure planning is actually a comprehensive planning-scale approach that identifies these hubs and corridors, integrating outdoor recreation, open space, cultural resources and conservation lands. Strategically linking linear land corridors maximizes environmental, habitat and outdoor recreation resources to meet the needs of growing populations. Used prior to development, the planning model identifies and ranks vital natural resources in concert with other community needs and gray infrastructure (pipes, pavement, mechanical systems, etc. that support community functions. Land development and growth is then guided in ways that accommodate increased populations while protecting natural resources, thereby providing long-term economic viability and community sustainability.

While green infrastructure-type comprehensive planning is beyond the scope of this Handbook, it is important for site and stormwater designers to understand the natural linkages of this approach with site and stormwater design. Environmental Site Design practices, which are discussed in **Chapter 6** this Handbook, promote preserving open space and sensitive resources and minimizing impervious cover. The open spaces preserved on a site provide more impact when they are linked with identified green infrastructure hubs and corridors to strengthen the green system. At the scale of BMP selection and design, focusing on runoff reduction carries this approach even further, to the micro-site scale, helping to replicate existing site hydrology and runoff characteristics, while minimizing negative impacts on the natural stream system that is part of our green infrastructure.

Emerging green design techniques for managing stormwater present a new pollution control philosophy based on the known benefits of natural systems, which provide multimedia pollution reduction and use soil and vegetation for the trapping, treating, filtration, infiltration and evapotranspiration of stormwater. The communities already using these techniques are finding that they provide a viable alternative to traditional stormwater management methods.

In addition to removing pollution from runoff, this more holistic approach reduces and delays runoff volumes, enhances groundwater recharge, protects surface water from stormwater runoff, increases carbon sequestration, mitigates urban heat island effects, improves air quality, increases wildlife habitat, and results in better urban aesthetics. In other words, *this approach more closely replicates the pre-development hydrology and runoff characteristics of the site.*

Although used widely overseas, particularly in Germany and Japan, the use of this approach in the United States is still in its infancy. However, data indicate that it can effectively reduce stormwater runoff and remove stormwater pollutants. Communities that have implemented green design are already reaping the benefits.

The urban landscape, with its large areas of impermeable roadways and buildings (impervious surfaces) has significantly altered the movement of water through the environment. Over 100 million acres of land have been developed in the United States, and with development and sprawl increasing at a rate faster than population growth, urbanization's negative impact on water quality is a problem that won't be going away. To counteract the effects of urbanization, communities are beginning to promote site designs that intercept precipitation and allow it to infiltrate, rather than being collected on and conveyed from impervious surfaces.

Each year, the rain and snow that falls on urban areas in the United States results in billions of gallons of stormwater runoff and combined sewer overflows (CSOs). Green design techniques reduce the amount of pollution introduced into waterways and help to relieve the strain on stormwater and wastewater infrastructure. Efforts in many cities have shown that this approach can be used to reduce the amount of stormwater discharged or entering combined sewer systems and that it can be cost-competitive with conventional stormwater and CSO controls.

This new approach to site and stormwater design is also unique because it offers an alternative land development approach. New developments that incorporate these techniques often cost less to build because of decreased site development and conventional infrastructure costs. Furthermore, such developments are often more attractive to buyers because of environmental amenities. The flexible and decentralized qualities of this approach also allow it to be retrofitted into developed areas to provide stormwater control on a site-specific basis. The techniques can be integrated into redevelopment efforts ranging from a single lot to an entire citywide plan.

Nonetheless, wider adoption of this new design approach still faces obstacles. Among these is the economic investment that is required across the country for adequate stormwater and CSO control. Although these techniques are in many cases less costly than traditional methods of stormwater and sewer overflow control, some municipalities persist in investing only in existing conventional controls rather than trying an alternative approach. Local decision makers and organizations must take the lead in promoting a cleaner, more environmentally beneficial method of reducing the water pollution that affects their communities. The DEQ recommends that local decision makers institute the following policies to promote the use of green infrastructure:

1. **Develop with green design and pollution management in mind.** Build green space into new development plans and aim to preserve as much existing vegetation as is feasible.

2. **Incorporate green design into long- term control plans for managing combined sewer overflows.** Green techniques can be incorporated into plans for infrastructure repairs and upgrades.

3. **Revise local stormwater regulations to encourage green design.** A policy emphasis should be placed on reducing impervious surfaces, preserving vegetation, capturing runoff on-site, providing water quality improvements, and protecting receiving streams from runoff-related damage. *(NRDC – "Rooftops to Rivers")*

4. **Incorporate stormwater management, including environmental site design techniques that reduce imperviousness, in the early planning stages of development projects and community growth strategies.** Retrofitting existing development with BMPs is much more technically difficult and costly, because the space may not be available, other infrastructure is already installed, and/or utilities may interfere. There may also be easements dedicated to homeowner's associations or other entities that present regulatory limitations to what can be done. Because of these kinds of barriers, retrofitting existing urban areas often depends on the use of engineered or manufactured BMPs, which are more expensive for both construction and operation (NRC, 2008).

In support of these concepts, the Water Science and Technology Board of the National Research Council has recently recommended that "[f]uture development and water resource protection plans should consider reducing impervious cover in the potential expansion of communities" (NRC, 2008, pg. 119). Examples of this include encouraging residential cluster developments, building taller buildings, reducing the width of residential streets, creating one-side sidewalks, reducing the size of parking lots to satisfy average parking needs rather than peak requirements, and using permeable pavement in overflow parking lots. In so doing, traditional impervious cover could be reduced 10-50 percent (NRC, 2008, pg. 122).

5.2.1 What Is the Green Infrastructure Approach?

In the *green infrastructure* approach, centralized treatment and/or storage facilities located at the "end of pipe" discharge from developed sites are classified as structural BMPs. While structural BMPs such as stormwater ponds and wetlands can be effective in controlling peak flows from the site, current regulatory requirements for these structures do not address the frequent storms that erode stream banks, and do little or nothing to promote recharge. Furthermore, structural BMPs can contribute to downstream flooding when discharges from separate on-site structural BMPs overlap. Structural BMPs can be effective in pollutant removal; but since they generally omit groundwater recharge, consume space, and require extensive maintenance, they are less appropriate for the task. There is an emerging recognition that wet detention structural BMPs contribute to elevated stream temperatures, and discharge algae laden effluent, which can substantially degrade the benthic community in the receiving stream.

As a result, many progressive agencies are promoting the green infrastructure approach, which is designed to intercept runoff from rooftops, parking lots and roads as close as possible to its source, and direct it into vegetative recharge/filtration facilities incorporated into the overall site design and runoff conveyance system. Green infrastructure design techniques described in this Handbook include environmental site design, impervious area disconnection, conveyance of runoff through filter strips and swales, terraces, bioretention facilities, and recharge through infiltration facilities. These design techniques and BMPs form the basis of green infrastructure at the site engineering level.

Since these vegetated structures do not rely on detention, these BMPs are "Green". However, while green infrastructure BMPs may seem less complex than structural detention measures, procedures for their proper design require the same hydrologic and hydraulic methods used in designing structural BMPs. The use of green design also involves a quantitative approach for reducing runoff volume and estimating pollutant loads, as well as projecting how well a particular design will remove such pollutants. Hence it is a "Technology", capable of providing realistic estimates of pollutant loading and removal, while also addressing hydrologic and hydraulic parameters involved in urban site design.

5.2.2 The Treatment Train Approach

Many, if not most, development sites will need to employ multiple practices in order to satisfy the nutrient reduction requirements in the Regulations and adequately manage stormwater runoff. Under the treatment train approach, stormwater management begins at the site level with simple methods that (1) minimize the amount of runoff from the site, and (2) prevent pollution from accumulating on the land surface and becoming available for transport in site runoff. This approach relies heavily on Better/Environmental Site Design, pollution source controls, and non-structural SCMs). **Figure 5.1** below illustrates this "treatment train" approach.

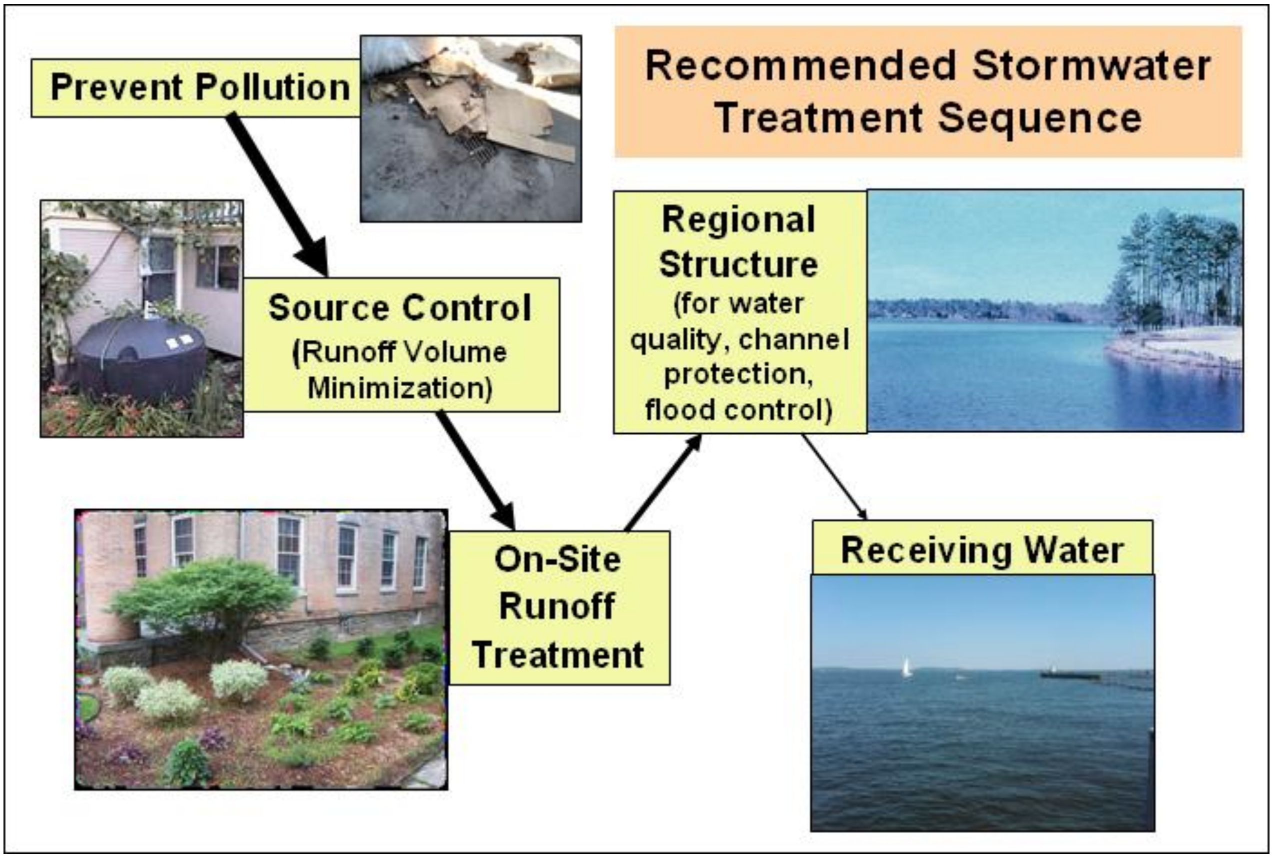

Figure 5.1: Treatment Train Approach for Stormwater Management (Adapted from MPCA, 2005)

As noted above, to be most effective and least costly, stormwater management plans should be conceived in the early planning stages of development projects. Most important, stormwater management plans using the green infrastructure approach organize the BMPs in a way that mimics the natural hydrology of the site. Thus, rainfall travels from the roof to the stream through a series of practices spread throughout the entire development site. **Table 5.1** lists groups of practices that reflect this order. No BMP should be considered for use without first considering those that precede it on this list. For example, environmental site design techniques, such as conserving or restoring open space and natural areas or minimizing impervious coverage through narrower streets, clustering, etc. are the first step. At this stage, pollution prevention practices are also applied to minimize the amount of pollutants that are available to wash off the site in stormwater runoff.

Then initial capture practices are applied, such as green roofs, rainwater harvesting (rain tanks and cisterns), or downspout disconnection are applied. Remaining runoff would then be directed to practices such as grass filters or dry swales, which might drain into bioretention or infiltration structures. This approach minimizes the amount of runoff generated and captures much of the runoff along the pathway to the development site outfall. If additional treatment or volume mitigation is needed, a pond or constructed wetland might be installed at the downstream end of the development site, as the final practice in the treatment train.

Table 5.1. Summary of Stormwater Control Measure (SCM) Categories

Stormwater Control Measure	When Used?[1]	Where Installed?[2]	Who Is Responsible?[3]	Hydrologic Control Objectives[4]	Water Quality Objectives[5]	Est. Maint. Protocols[6]
1. Product Substitution (lead-free gasoline, ethanol, P-free detergent, etc.) [7]	Continuous	State, regional	Regulatory agencies	NA[8]	Prevention	NA
2. Watershed and Land-Use Planning	Planning stage	Watershed	Local planning agencies	All objectives	Prevention	Yes
3. Conservation of Natural Areas	Site and watershed planning stage	Site, watershed	Developer, local planning agency	Prevention	Prevention	Yes
4. Impervious Cover Minimization	Site planning stage	Site	Developer, local review authority	Prevention & reduction	Prevention	No
5. Earthwork Minimization	Grading plan	Site	Developer, local review authority	Prevention	Prevention	Yes
6. Erosion and Sediment Control	Construction	Site	Developer, local review authority	Prevention & reduction	Prevention and removal	Yes
7. Reforestation and Soil Conservation[9]	Site planning and construction	Site	Developer, local review authority	Prevention & reduction	Prevention	No
8. Pollution Prevention SCMs for Stormwater Hotspots	Post-construction or retrofit	Site	Operators and local and state permitting agencies	NA	Prevention	No
9. Runoff Volume Reduction – Rainwater Harvesting	Post-construction or retrofit	Rooftop	Developer, local planning agency and review authority	Reduction	Removal	Yes
10. Runoff Volume Reduction – Vegetated (Green roofs, Bioretention, Bioinfiltration, Bioswales)	Post-construction or retrofit	Site	Developer, local planning agency and review authority	Reduction & some peak attenuation	Removal	Emerging
11. Runoff Volume Reduction – Subsurface (Infiltration Trenches, Permeable Pavement)	Post-construction or retrofit	Site	Developer, local planning agency and review authority	Reduction & some peak attenuation	Removal	Yes
12. Peak Reduction and Runoff Treatment (Stormwater Wetlands, Dry/E.D. Ponds)	Post-construction or retrofit	Site	Developer, local planning agency and review authority	Peak attenuation	Removal	Yes
13. Runoff Treatment (Sand Filters, Manufactured Treatment Devices)	Post-construction or retrofit	Site	Developer, local planning agency and review authority	None	Removal	Yes
14. Aquatic Buffers and Managed Floodplains	Planning, construction and post-construction	Stream corridor and sinkholes	Developer, local planning agency and review authority, landowners	NA	Prevention and removal	Emerging
15. Stream Rehabilitation	Post-development	Stream corridor	Local planning agency and review authority	NA	Prevention and removal	Unknown
16. Municipal Housekeeping (Street Sweeping, Storm Drain Cleanouts)	Post-development	Streets and stormwater infrastructure	MS4 permittee	NA	Removal	Emerging
17. Illicit Discharge Detection and Elimination	Post-development	Stormwater infrastructure	MS4 permittee	NA	Prevention and removal	No
18. Stormwater Education	Post-development	Stormwater infrastructure	MS4 permittee	Prevention	Prevention	Emerging
19. Residential Stewardship	Post-development	Stormwater infrastructure	MS4 permittee	Prevention	Prevention	No

TABLE NOTES:

[1] At which stage of the development cycle is the practice applied?

[2] Location/scale in the site/watershed where the practice is installed?

[3] Who is responsible for implementing the practice?

[4] Prevention = prevents generation of runoff; Reduction = reduces volume of runoff; Treatment = delays runoff delivery only; Peak Attenuation = reduction of peak flows through detention

[5] Prevention = prevents generation, accumulation, or wash-off of pollutants and/or reduces runoff volume; Removal = reduces pollutant concentrations in runoff by physical, chemical or biological means

[6] No = extremely limited understanding of procedures to maintain BMP in the future; Emerging = still learning about how to maintain the BMP; Yes = solid understanding of maintenance for future BMP needs

[7] Italics = Nonstructural BMPs

[8] NA = Not Applicable for the BMP

[9] Shaded rows correspond to Runoff Reduction Method and BMPs shown in **Table 5.5**

Source: Adapted from NRC, 2008

As noted above, these measures often result in significant cost savings for development projects, even when land costs are factored. Once efforts to minimize runoff volume and stormwater pollution are identified, the next step is to select structural stormwater BMPs, or groups of BMPs, aimed at collecting and treating the runoff that is generated.

The following provides additional information about each step in the treatment train approach to BMP selection. Included in the discussion are examples of some of the different structural and non-structural BMPs that can be employed during each step of the BMP selection process at a development site.

5.2.2.1 Pollution Prevention

The first step in effectively managing stormwater is to identify opportunities for stormwater pollution prevention. Stormwater pollution prevention is aimed at reducing and/or preventing the contamination of stormwater runoff at its source, *before* it has an opportunity to pollute the runoff flow and enter the conveyance system. Stormwater pollution prevention practices, also know as *"source controls,"* are an important way to prevent water quality problems in stormwater runoff from a variety of sources. The intent of source control practices is to prevent stormwater from coming in contact with pollutants in the first place rather than having to use downstream structural controls to treat the runoff and remove pollutants. Examples include keeping impervious surfaces clean and handling and storing chemicals properly.

The pollution prevention practices that can be used depend on whether the land use is residential, commercial, industrial, institutional, or municipal development. The nature and distribution of pollutant sources are different at every development site and, therefore, the practices that are used are unique to each site. **Table 5.2** below illustrates some of the common pollution prevention practices used in both residential and non-residential developments.

Promoting Pollution Prevention Management Practices

A community should actively promote the use of stormwater pollution prevention management practices by local businesses, industries, and institutions. This is ideally done through the adoption of a compendium of pollution prevention practices by communities. Both existing and new development can be required to prepare a stormwater pollution prevention plan (SWPPP) as a condition of a business or operation permit, or as part of an overall stormwater management site plan.

Table 5.2. Common Pollution Prevention Practices (Source Controls)

Residential Developments	Non-Residential Developments
• Product Substitution • Natural Landscaping • Tree Planting • Yard Waste Composting • Septic System Maintenance • Driveway/Parking Lot/Street Sweeping • Materials Management • Household Hazardous Waste Collection Programs • Car Fluid Collection and Recycling Programs • Downspout Disconnection • Pet Waste Pickup • Storm Drain Marking • Storm Drain Maintenance	• Covered Loading Areas • Fuel Containment Areas • Covered Vehicle Storage Areas • Removal of Illicit Storm Drain Connections • Catch Basin Cleanout • Downspout Disconnection • Covered Dumpsters • Prevention of Illegal Dumping • Covered Materials Storage Areas • Secondary Containment Structures • Spill Prevention and Response Plans • Signage • Employee Training

Brochures and fact sheets containing relevant pollution prevention practices as well as training programs and/or videos can be made available for specific commercial and industrial categories (such as restaurants, gas stations, or concrete operations) to provide business owners and employees with the necessary tools to preventing stormwater contamination in their activities and operations. More specific information about public information and education programs can be found in **Section 8.2.16** of **Chapter 8** in this Handbook.

Municipal Housekeeping

The first role of a local government is to prevent stormwater pollution by setting the example. A community should implement relevant pollution prevention practices in all areas of local government operations and activities. This can include such things as:

- Material Storage Practices
- Waste Reduction and Disposal
- Fleet Vehicle Maintenance
- Building and Grounds Maintenance
- Construction Activities

Though often associated with public works departments, housekeeping activities should be implemented across the entire spectrum of local agencies and entities, including locally-owned utilities (e.g. water and wastewater facilities and operations), parks and recreation departments, school districts, public hospitals, administrative offices, and other publicly-owned facilities.

Municipal facilities and operations should prepare a stormwater pollution prevention plan as well as a spill prevention plan, if applicable. These plans should include provisions for how a department or agency plans to reduce pollutant runoff from their site, including reducing exposure of potential pollutants and removing pollutants discharged from their site. Regular visits and inspections of each facility would be performed to insure compliance with these plans. A training program and/or video on stormwater issues and pollution prevention can be developed and provided for public employees.

Hazardous Household Waste Management

Household hazardous wastes can include a wide variety of materials used in the home, including paints, solvents, pesticides, herbicides and cleaners. Residents often dispose of the unused portion of these products down a drain (which goes to the wastewater treatment plan or septic tank), or they may dump them in their yard, a storm drain or a drainage ditch or stream. They may also put them in their trash can, for ultimate disposal in the local solid waste landfill. These faulty disposal strategies result in harm to bacteria in wastewater treatment plants or septic systems that digest or break down wastes, or direct pollution to streams, or the risk of long-term infusion of pollutants into the soil and, ultimately, the groundwater at landfill sites.

Ideally, a community should establish a collection center for household hazardous wastes. Citizens would be able to drop off their wastes, which can then be categorized and disposed of at an approved hazardous waste facility. An alternative is for the community to hold household hazardous waste drop-off days 2-4 times a year, where citizens can bring their waste materials to drop-off sites, and the community then categorizes and disposes of the materials. The cost of such operations can be borne through fees/per volume of material or absorbed into the fee structure of a local stormwater utility. A complementary option is to encourage the use of non-hazardous or less-hazardous alternatives for particular products.

Street Sweeping

Street and parking lot sweeping on a regular basis can remove sediment debris, litter and other pollutants from road and parking lot surfaces that are potential sources of stormwater pollution. Recent improvements in street sweeper technology have enhanced the ability of machines to pick up fine-grained sediment particles that carry a substantial portion of the stormwater pollutant load.

The frequency of and location of street sweeping is an important consideration for any program. How often and where to sweep are determined by the program budget and the level of pollutant removal the community wishes to achieve.

Dry Weather Outfall Screening / Illicit Connection Removal

A community should have an active dry weather outfall screening program to identify and eliminate illicit or illegal discharges from entering the stormwater drainage system. These discharges can include a variety of commercial, industrial or manufacturing process water discharges, floor drains from businesses or industrial locations, or even illicit sanitary sewer connections. They are generally characterized by continuous or periodic discharges which occur during dry and wet weather and contain pollutants that should not be discharged to surface waters.

A number of different procedures can be used to identify illicit connections and discharges into the stormwater drainage system. Once they have been identified, they should be eliminated under the authority of existing local ordinances or by referring the matter to the appropriate state agency. Information on what are appropriate connections to the stormwater drainage system should be provided to developers and contractors to prevent future illicit connections.

Sanitary Sewer Maintenance

Leaking sanitary sewer lines located near storm sewer pipes, paved channels and streams can add pathogens as well as nutrients such as nitrogen and phosphorus to stormwater and surface waters. Human waste also contributes to biological oxygen demand (BOD). Inspections and leak detection of sanitary sewer lines should be conducted on a regular basis as part of an operations and maintenance program for a local wastewater utility, public works department, or other responsible entity.

Septic Tank Maintenance

Effluent from poorly maintained or failing septic systems can rise to the surface and contaminate stormwater runoff. Improperly maintained septic systems can be potentially significant sources of pathogens and nutrients, especially nitrogen to stormwater runoff. In order to combat this problem, communities need to promote or require the regular maintenance of septic tank systems. A local jurisdiction can track septic tanks in a database, and send out notices at the required interval for septic tank inspections and maintenance. Septic tanks can also be permitted by a local jurisdiction, with permit renewal contingent on certification of septic tank maintenance.

Landfills

Improperly maintained landfills can allow litter, nutrients, pathogens and toxic contaminants to reach or stay on the surface of the landfill, allowing runoff to carry these pollutants to nearby water bodies. Therefore, it is important that a community regulate landfills to require the appropriate management measures to keep contaminated runoff from leaving the landfill site.

Pollution Reporting Hotline / Spill Response

Local citizens can be helpful eyes and ears by reporting water quality problems and polluting activities. A community should have procedures for reporting stormwater polluters and promptly responding to emergencies such as hazardous materials spills. A telephone hotline could be established for receiving calls about water pollution, polluters and spills. It would be preferable for this number to be manned 24 hours a day or at least for extended daily hours.

More guidance for establishing an effective local stormwater pollution prevention program can be found in **Chapter 8** of this Handbook. Even more detailed guidance about pollution prevention measures can be found in Manual #9 of the Center for Watershed Protection's *Urban Subwatershed Restoration Manual Series*, entitled ***Municipal Pollution Prevention / Good Housekeeping Practices*** (June 2008). The USEPA web site is also a good source for guidance on many of these source control types of practices, at:

http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=min_measure&min_measure_id=6

5.2.2.2 Runoff Volume Reduction

The next step in effectively managing stormwater is to identify opportunities for runoff volume reduction and/or groundwater recharge at the development site, which can reduce the generation of stormwater runoff. These BMPs typically have the effect of reducing the amount of impervious cover and the amount of stormwater runoff that must be controlled, which can save space and reduce the cost of BMPs at the site. **Table 5.3** lists some of the common BMPs used to reduce runoff volumes at development sites. **Figure 5.2** is a cluster development that conserves natural open space for common use and reduces the amount of streets and utilities needed to serve the community. **Figure 5.3** is an example of a Green Street design, incorporating several of these concepts. This location, part of the Natural Drainage Systems Project in Seattle, Washington, exhibits several elements of impervious cover reduction. In particular, vegetated swales were installed and curbs and gutters removed. There are sidewalks on only one side of the street, and they are separated from the road by the swales. The residences' rooftops have been disconnected from the storm drain systems and are redirected into the swales.

Table 5.3.Common ESD Techniques and BMPs Used to Reduce Runoff Volume

Runoff Reduction Measures	
• Natural Area Conservation • Site Reforestation • Prairie/Meadow Restoration • Stream and Shoreline Buffers • Soil Amendments • Impervious Cover Disconnection • Downspout Disconnection • Open Space Subdivision • Design Grass Channels • Bioretention	• Filtration • Infiltration • Dry Swales • Filter Strips (Sheet Flow to Open Space) • Reduced Street Width • Reduced Sidewalks • Smaller and/or Vegetated Cul-de-sacs • Shorter Driveways • Green Parking Lots and Driveways • Shared Parking Lots and Driveways

Figure 5.2. Cluster Development

Figure 5.3. Green Street Design for 110th Street, Seattle, WA
(Source: Seattle Public Utilities)

In the past, using these kinds of site design techniques, such as preserving open space to reduce runoff volume, did not translate into any kind of economically tangible credit for developers in Virginia. However, that is no longer true. Runoff volume calculations using the new Runoff Reduction Method (discussed below) will generate smaller amounts of site runoff where land cover is preserved that produces less runoff. This will translate into fewer and/or smaller BMPs needed on the site to manage the runoff. **Chapter 6** will provide more specific guidance about Environmental Site Design techniques.

5.2.2.3 On-Site and Off-Site Structural Stormwater Treatment

The final step in managing site stormwater effectively is to select individual structural stormwater BMPs, or groups of structural BMPs, aimed at collecting and treating runoff either on-site or off-site. These structural BMPs include:

- Runoff Volume Reduction (including Vegetated Roofs and Rainwater Harvesting)
- Grass Swales or Open Channels (including Dry Swales and Wet Swales)
- Filtration (including Filters and Biofiltration)
- Infiltration (including Permeable Pavement and Bioinfiltration)
- Stormwater Basins (Constructed Wetlands, Wet ponds, and Extended Detention)

5.2.2.4 Use of Proprietary BMPs

There is a plethora of proprietary and experimental stormwater technologies on the market. Adding these practices to the list provides designers with more flexibility to comply with stormwater requirements in difficult development situations. On the other hand, the performance of many of these products still remains largely unproven, and their real world maintenance burden is largely unknown. In addition, many vendors make extravagant claims about performance and can be very aggressive about getting their products added to the list of BMPs approved for use. The DEQ, in cooperation with the Virginia Water Resource Research Center at Virginia Tech, has established a process for evaluating and certifying manufactured treatment devices (MTDs) for use in the state. A list of approved MTDs, at several levels of certification, is provided on the Virginia Stormwater BMP Clearinghouse web site, at http://www.vwrrc.vt.edu/swc/ .

5.3 THE VIRGINIA APPROACH

5.3.1 Site-Based Nutrient Load Limits

The Runoff Reduction Method for Virginia is focused on site compliance to meet a site-based load limit for Total Phosphorus (TP) of 0.41 lbs./acre/year. This means that the proposed Virginia stormwater regulations are aimed at limiting the total load of Phosphorus leaving a new development site. This is a departure from water quality computations of the past, in which the analysis focused on comparing the post-development site condition to the pre-development condition, or an average land cover condition. The chief objective of instituting a site-based load limit is so that land, as it develops, can still meet the nutrient reduction goals outlined in the Chesapeake Bay Tributary Nutrient Reduction Strategies.

With the site-based limit, newly-developed land will maintain loadings that replicate existing loading from agricultural, forested and mixed-open land uses, where there is no impervious cover. This is not to say that all developing parcels will maintain the pre-development loading rates, but that the rates, averaged across all development sites, will not increase when compared with loading rates from non-urban land.

An operational advantage to using site-based load limits is that it simplifies computations by focusing on the post-development condition. This should reduce time-consuming conflict between site designers and local government plan reviewers by eliminating disagreements about how to characterize the pre-development condition for a particular site.

Stakeholders participating on Advisory Committee’s for the Stormwater Management Regulation revision process advised that Virginia should continue to use Total Phosphorus (TP) as the “indicator” pollutant of choice for stormwater regulation purposes. There are numerous practical and scientific reasons for this choice, but stakeholders also acknowledged that developers and consultants in Virginia are used to addressing TP, and continuing to use it would avoid unnecessary confusion. The load limit decided upon for Total Phosphorus is based on the TP load associated with an imperviousness threshold of 10 percent across a small watershed (as opposed to a river basin). Using the Center for Watershed Protection’s *Impervious Cover Model* (see **Appendix 5-A** of this chapter), 10 percent is the upper limit of the range of imperviousness that results in stream degradation. So the goal would be to keep watershed imperviousness below 10 percent to avoid degradation of local streams and, subsequently, the Chesapeake Bay or other rivers fed by those streams.

5.3.2 Runoff Coefficients – Moving Beyond Impervious Cover

The negative impacts of increased impervious cover (IC) on receiving water bodies have been well documented (CWP 2003, Walsh et al. 2004; Shuster et al. 2005; Bilkovic et al. 2006). Due to widespread acceptance of this relationship, IC has frequently been used in watershed and site design efforts as a chief indicator of stormwater impacts.

More recent research, however, indicates that other land covers, such as disturbed soils and managed turf, also impact stormwater quality (Law et al, 2008). Numerous studies have documented the impact of grading and construction on the compaction of soils, as measured by increase in bulk density, declines in soil permeability, and increases in the runoff coefficient (OCSCD et al, 2001; Pitt et al, 2002; Schueler and Holland, 2000). These areas of compacted pervious cover (lawn or turf) have a much greater hydrologic response to rainfall than forest or pasture.

Further, highly managed turf can contribute to elevated nutrient loads. Typical turf management activities include mowing, active recreational use, and fertilizer and pesticide applications (Robbins and Birkenholtz 2003). An analysis of Virginia-specific data from the National Stormwater Quality Database (Pitt et al. 2004) found that runoff from monitoring residential sites with relatively low IC contained significantly higher nutrient concentrations than sites with higher IC non-residential uses (CWP & VA DCR, 2007). This suggests that residential areas with relatively low IC can have disturbed and intensively managed pervious areas that contribute to elevated nutrient levels.

The failure to account for the altered characteristics of disturbed urban soils and managed turf can result in an underestimation of stormwater runoff and pollutant loads generated from urban pervious areas. Therefore, Virginia's new Runoff Reduction Method, the computation procedure for complying with the nutrient reduction requirements in the regulations, accounts for both impervious cover and other important land cover types. The runoff coefficients provided in **Table 5.4** were derived from research by Pitt et al (2005), Lichter and Lindsey (1994), Schueler (2001a), Schueler, (2001b), Legg et al (1996), Pitt et al (1999), Schueler (1987) and Cappiella et al (2005). As shown in this table, the effect of grading, site disturbance, and soil compaction greatly increases the runoff coefficient compared to forested areas.

Table 5.4. Site Cover Runoff Coefficients (R_V)

Soil Condition	Runoff Coefficient
Forest Cover	0.02 to 0.05*
Disturbed Soils/Managed Turf	0.15 to 0.25*
Impervious Cover	0.95
*Range dependent on original Hydrologic Soil Group (HSG), as follows: For Forest: A = 0.02; B = 0.03; C = 0.04; and D = 0.05 For Disturbed Soils: A = 0.15; B = 0.20; C = 0.22; and D = 0.25	

5.3.3 Treatment Volume – The Common Currency for Site Compliance

Treatment Volume (T_v) is the central component of the Runoff Reduction method. By applying site design, structural, and nonstructural practices, the designer can reduce the treatment volume by reducing the overall volume of runoff leaving a site. In this regard, the Treatment Volume is the main "currency" for site compliance.

As explained more fully in **Chapter 10** (***Unified Sizing Criteria***), Treatment Volume is a variation of the 90% capture rule that is based on a regional analysis of the mid-Atlantic rainfall frequency spectrum. In Virginia, the 90th percentile rainfall event is defined approximately as 1-inch of rainfall.

The rationale for using the 90th percentile event is that it represents the majority of runoff volume on an annual basis. Larger events would be very difficult and costly to control for the same level of water quality protection (as indicated by the upward inflection at 90%). However, by controlling the 1-inch rainfall event, these larger storm events would also receive partial treatment for water quality, as well as storage for channel protection and flood control.

The proposed Treatment Volume (T_v) has several distinct advantages when it comes to evaluating runoff reduction practices and sizing BMPs:

- The T_v provides effective stormwater treatment for approximately 90% of the annual runoff volume from the site, and larger storms will be partially treated.

- Storage is a direct function of impervious cover and disturbed soils, which provides designers incentives to minimize the area of both at a site.

- Using the 90% storm event to define the T_v is widely accepted and is consistent with other state stormwater manuals (MDE, 2000; ARC, 2002; NYDEC, 2001; VTDEC, 2002; OME, 2003; MPCA, 2005).

- The T_v approach provides adequate storage to treat pollutants for a range of storm events. This is important since the first flush effect has been found to be modest for many pollutants (Pitt et al, 2005).

- T_v provides an objective measure to gage the aggregate performance of environmental site design, LID and other innovative practices, and conventional BMPs together using a common currency (runoff volume).

- Calculating the T_v explicitly acknowledges the difference between forest and turf cover and disturbed and undisturbed soils. This creates incentives to conserve forests and reduce mass grading and provides a defensible basis for computing runoff reduction volumes for these actions.

5.3.4 The Runoff Reduction Method

At the core of Virginia's green infrastructure approach to stormwater management is a new *Runoff Reduction (RR) Method*, developed with assistance from the Center for Watershed Protection and the Chesapeake Stormwater Network. This methodology was developed in order to promote better stormwater design and as a tool for compliance with the Virginia Stormwater Management Regulations and is explained more thoroughly in **Chapter 12** of this Handbook. There are several shortcomings to existing stormwater design practices that the Runoff Reduction Method seeks to overcome, as follows:

- **Leveling the BMP Playing Field.** The suite of BMPs that has been available up to now in Virginia has been somewhat limited. There are many new and innovative practices that have proven effective at reducing runoff volumes and pollutant loads. In particular, good site design practices, that reduce stormwater impacts through design techniques, are not "credited" in the existing system. The RR Method puts traditional and innovative BMPs on a level playing field in terms of BMP selection and site compliance.

- **Meeting the Big-Picture Goals.** The existing stormwater compliance system does not meet Chesapeake Bay Tributary Strategy nutrient reduction goals for urban land. As sites are developed, the nutrient loads from urban land increase at a rate that exceeds urban land targets. The RR Method uses better science and improved BMP specifications to help with the job of incrementally attaining the Tributary Strategy goals for phosphorus and nitrogen.

- **Moving Beyond Addressing Only Impervious Cover.** Previous computation procedures used impervious cover as the sole indicator of a site's water quality impacts. More recent research indicates that a broad range of land covers – including forest, disturbed soils, and managed turf – are significant indicators of water quality and the health of receiving streams. The RR Method accounts for these land covers and provides built-in incentives – those credits that were not previously available – to protect or restore forest cover and reduce impervious cover and disturbed soils.

- **Moving Towards Total BMP Performance.** The previous system for measuring BMP effectiveness was based solely on the pollutant removal functions of the BMP, but did not account for the BMP's ability to reduce the overall volume of runoff. Recent research has shown that BMPs are quite variable in terms of providing runoff reduction, and some achieve very positive results. Runoff reduction has benefits beyond pollutant load reductions. BMPs that reduce runoff volumes can do a better job of replicating pre-development hydrologic conditions, protecting downstream channels, recharging groundwater, and, in some cases, reducing overbank (or "nuisance") flooding conditions. The RR Method uses recent research on runoff reduction to better gage total BMP performance.

- **Providing Accountability for Design.** Previously, it could be difficult for site designers and plan reviewers to verify BMP design features – such as sizing, pretreatment, and vegetation – that should be included on stormwater plans in order to achieve a target level of pollutant removal. Clearly, certain BMP design features either enhance or diminish overall pollutant removal performance. The RR Method provides clear guidance that links design features with performance by distinguishing between "Level 1" and "Level 2" designs.

As noted above, the RR Method relies on a three-step compliance procedure, as follows:

- **Step 1: Apply Site Design Practices to Minimize Impervious Cover, Grading and Loss of Forest Cover.** This step focuses on implementing Environmental Site Design (ESD) practices during the early phases of site layout. The goal is to minimize impervious cover and mass grading, and to maximize retention of forest cover, natural areas and undisturbed soils (especially those most conducive to landscape-scale infiltration). The RR Method uses a spreadsheet to compute a composite runoff coefficient for forest, disturbed soils, and impervious cover and to calculate a site-specific target treatment volume and Phosphorus load reduction target, based on criteria in the Virginia Stormwater Management Regulations.

- **Step 2: Apply Runoff Reduction (RR) Practices.** In this step, the designer considers possible combinations of RR practices on the site. In each case, the designer estimates the area to be treated by each RR practice to incrementally reduce the required treatment volume for the site. The designer is encouraged to use RR practices in series (i.e., *treatment trains*) within individual drainage areas (e.g., rooftop disconnection to a grass swale to a bioretention area) in order to achieve a higher level of runoff reduction.

- **Step 3: Compute the Pollution Removal (PR) of the Selected BMPs.** In this step, the designer uses the spreadsheet tool to see whether the required phosphorus load reduction has been achieved by the application of RR practices.

- **Step 4:** If the target phosphorus load limit is not reached, the designer can select additional BMPs that provide no runoff reduction but only treatment (e.g., filtering practices, wet ponds, stormwater wetlands, etc.) to meet the remaining load reduction requirement.

In reality, the process is *iterative* for most sites. When compliance cannot be achieved on the first try, designers can return to prior steps to explore alternative combinations of Environmental Site Design, Runoff Reduction practices, and Pollutant Removal practices to achieve compliance. A **possible Step 5** would involve paying an offset fee (or fee-in-lieu payment) or providing off-site mitigation, where such options are provided for by the local stormwater management program, to compensate for any load that cannot feasibly be met on a particular site. If the local government or program authority has a watershed or regional planning structure for stormwater management, it will be easier to apply such offset options to project sites within the jurisdiction. The amount of the fee will typically be driven by the "market," based on the phosphorus "deficit" – that is, the difference between the target reduction and the actual site reduction after the designer makes his or her best effort to apply Runoff Reduction and Pollutant Removal practices.

Common sense indicates that well-maintained and high quality long-term records of precipitation are "vital and nontrivial" for effective stormwater management programs. A network of precipitation gauge data is available online from the National Climatic Data Center, at http://www.ncdc.noaa.gov/oa/ncdc.html, or the Cooperative Weather Observer Program, at http://www.nws.noaa.gov/om/coop/ . Additionally, the National Weather Service provides estimates of the return periods for a range of depth-duration storm events, available at http://www.nws.noaa.gov/om/coop/. Considering the implications of climate change discussed in **Chapter 4**, such that precipitation regimes are systematically being altered, it is paramount to update depth-duration-frequency curves in order to guarantee stormwater management facilities will be able to accommodate more intense precipitation.

Figure 5.4 is a flow chart illustrating the step-wise compliance process described above. **Table 5.5** includes a list of site design and stormwater practices that can be used for each step.

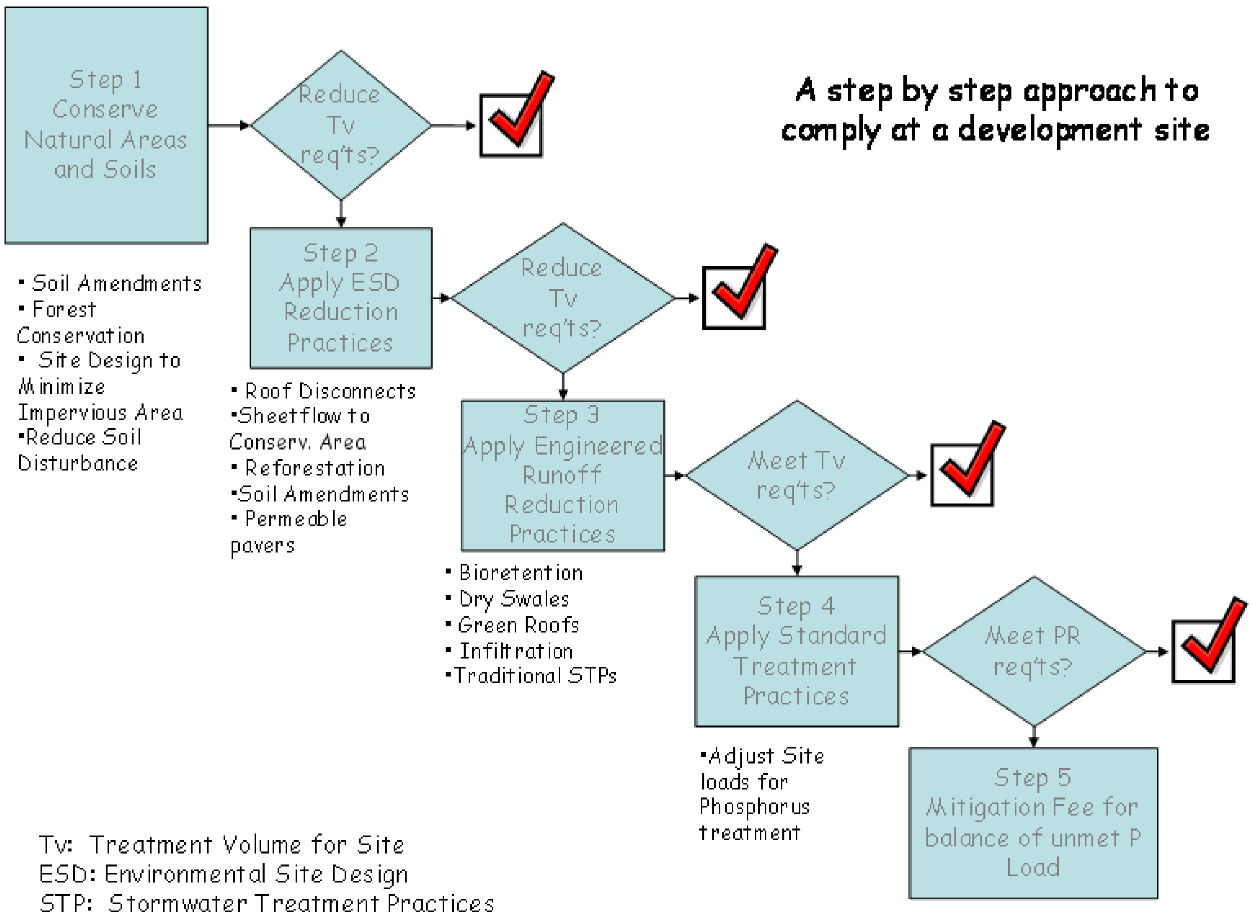

Figure 5.4. Step-Wise Process for Site Compliance

Table 5.5. Practices Included in the Runoff Reduction Method

<table>
<tr><th>Step 1: Environmental Site Design (ESD) Practices (see Control Measure #7 in Table 5.1)</th><th>Step 2: Runoff Reduction (RR) Practices (see Control Measures #s 9-11 in Table 5.1)</th><th>Step 3: Pollutant Removal (PR) Practices (see Control Measures #s 12-13 in Table 5.1)</th></tr>
<tr><td>Forest Conservation</td><td>Filter Strip (Sheet Flow to Conserved Open Space)</td><td>Filtering Practice</td></tr>
<tr><td>Site Reforestation</td><td rowspan="2">Rooftop Disconnection:
• Simple
• To Soil Amendments
• To a Rain Garden or Dry Well
• To a Rain Tank or Cistern</td><td>Constructed Wetland</td></tr>
<tr><td rowspan="1">Soil Restoration (combined with or separate from rooftop disconnection)</td><td>Wet Swale
Wet Pond</td></tr>
<tr><td rowspan="7">Site Design to Minimize Impervious Cover and Soil Disturbance</td><td>Vegetated roof</td><td></td></tr>
<tr><td colspan="2">Grass Channels</td></tr>
<tr><td colspan="2">Permeable Pavement</td></tr>
<tr><td colspan="2">Bioretention</td></tr>
<tr><td colspan="2">Dry Swale (Water Quality Swale)</td></tr>
<tr><td colspan="2">Infiltration</td></tr>
<tr><td colspan="2">Extended Detention (ED) Pond</td></tr>
<tr><td colspan="3">NOTE: Practices in shaded cells achieve both Runoff Reduction (RR) and Pollutant Removal (PR) functions, and they can be used for Steps 3 and 4 depicted in Figure 5.4.</td></tr>
</table>

5.4 THE CHALLENGES OF REDEVELOPMENT

Redevelopment is the process whereby an existing development is adaptively reused, rehabilitated, restored, renovated, and/or expanded, which results in disturbance or clearing of a defined footprint at the site. Redevelopment projects normally occur within dense urban watersheds that are served by existing water, sewer and other public infrastructure. When redevelopment is done properly, it is a key element of smart growth and sustainable development (USEPA, 2005b, 2006).

The potential for water quality improvements due to redevelopment stormwater requirements is significant. However, the challenges and constraints that the urban environment imposes on stormwater management at high intensity *redevelopment* projects are considerable. These challenges include physical, technological, economic and institutional impediments. To achieve effective stormwater management at redevelopment sites requires creative policy and engineering approaches at the state and local level.

Much of the confusion and some of the controversy associated with redevelopment are generated by vague or ambiguous regulatory definitions of redevelopment and their associated stormwater treatment requirements. Redevelopment is generally defined a s the process whereby an existing development is adaptively reused, rehabilitated, restored, renovated, and/or expanded, which results in disturbance or clearing of a defined footprint at the site. Redevelopment normally occurs within urban watersheds that are served by existing water, sewer and public infrastructure. When redevelopment is done properly, it is a key element of smart growth and sustainable development (CSN, 2011).

The Virginia Stormwater Management Regulation (4 VAC 50-60 et seq.) defines the term “prior developed lands” (rather than “redevelopment”) as follows:

> *Prior developed lands* means land that has been previously utilized for residential, commercial, industrial, institutional, recreation, transportation or utility facilities or structures, and that will have the impervious areas associated with those uses altered during a land-disturbing activity.

In the context of a local stormwater management program, it is useful to characterize what constitutes redevelopment in clear, measurable and operational terms, so that those who must comply with redevelopment requirements of the regulations can know exactly what is expected of them. The Virginia Stormwater Management Act allows localities the flexibility of establishing “more stringent” criteria, which might extend to clearer definitions of terms. Ideally, for a construction project to qualify as redevelopment, it should meet the criteria such as the following:

- *Minimum disturbance footprint:* This defines a minimum surface area of redevelopment activity that will be subject to stormwater requirements. In some jurisdictions around the Chesapeake Bay watershed, this threshold is as low as 250 square feet to as high as one acre.
- *Minimum amount of pre-existing impervious cover at the site:* A second threshold could be used to qualify a redevelopment project based on the existing impervious cover present at the site prior to construction (e.g., the site must have 40% or more existing impervious cover to be classified as redevelopment), while sites with less impervious cover are classified as new development. For example, this criterion might be applied to building sites only, and not to smaller VDOT roadway improvements.
- *Different treatment standards for existing impervious cover and new impervious cover created by the redevelopment project:* It is important to distinguish between these forms of total impervious cover at the site to ensure that higher treatment standards are in place for any new impervious cover that is created.
- *Less stringent stormwater performance standards as compared to new greenfield development projects:* This explicitly recognizes that redevelopment is desirable from the standpoint of smart growth.
- *Situations when it is permissible to shift from runoff reduction to water quality treatment:* The definition might specify the site conditions where full on-site infiltration or runoff reduction is not feasible or desirable at a redevelopment project. In these cases, designers would be allowed to shift to conventional stormwater practices to treat runoff quality. Examples might include brownfields, stormwater hotspots, and urban fill soils.

The Virginia Stormwater Management Regulations specify that stormwater treatment requirements only apply to the *disturbed area* of a redevelopment project, and not the entire property (e.g., if a strip shopping center is renovated but the parking lot is not disturbed, then stormwater requirements only apply to the building – in fact, if there is no *land* disturbance, then stormwater management requirements would not apply at all). The regulatory criteria make it easy to determine and verify what portion of a proposed redevelopment site will be subject to stormwater requirements, and which requirements will apply.

Virginia's requirements for redevelopment also clearly distinguish between *existing impervious cover* and *newly created impervious cover* at a redevelopment site. Stormwater treatment requirements are reduced for existing impervious cover (compared to green-fields. The situation reverses if the redevelopment project creates more impervious cover than the predevelopment condition. In this case, the new increment of impervious cover is subject to the higher stormwater treatment standards for new development (e.g., full water quality and channel protection). This creates a strong incentive to prevent creation of new or additional impervious cover at a redevelopment site.

Reflecting these concepts, the Virginia stormwater management regulatory criteria that apply to redevelopment projects are as follows:

- If the redevelopment project disturbs greater than or equal to 1 acre *and* there is *no increase* of total impervious cover from the pre-development condition, then the project must reduce the pre-development Total Phosphorus (TP) load by 20%.
- If the redevelopment project disturbs less than 1 acre *and* there is *no increase* of total impervious cover from the pre-development condition, then the project must reduce the pre-development TP load by 10%.
- If the redevelopment project results in a net increase in impervious cover over the pre-development condition, the design criteria for new development must be applied to the *increased* impervious area, while the appropriate redevelopment criteria above will apply to the existing impervious area, based on the size of the disturbed area.
- For linear redevelopment projects (e.g., VDOT roads), the TP load of the project occurring on prior developed land must be reduced 20% below the pre-development TP load.
- In any case, the TP load is *not* required to be reduced to below the standard for new development (0.41 lbs./acre/year of TP), *unless* a more stringent standard has been developed by the local stormwater management program.

Recognizing the many challenges regarding managing stormwater at redevelopment projects, stormwater managers and designers should not construe that stormwater treatment should be avoided at high intensity redevelopment sites. Rather, Virginia has crafted effective stormwater solutions that are specifically tailored to the unique conditions and economic realities found at redevelopment sites. **Appendix 5-C** of this chapter discusses the unique conditions at redevelopment projects and important considerations that apply to the management of stormwater on such sites.

5.5 STORMWATER CONTROL ON A WATERSHED SCALE

Implementing stormwater management on a site-by-site basis is the traditional mode of compliance in Virginia. This is largely due to the system of Land Use Law in Virginia, which vests authority for land use planning and decision-making with local governments. The reality is that few local governments have been willing to spend the money and perform the studies needed to support watershed-wide approaches to stormwater management, even though the Stormwater Management Law encourages and provides compliance incentives to do so. Comprehensive watershed-scale stormwater management plans provide the most efficient and flexible means of continuing to develop sensibly while still meeting stormwater regulatory criteria. The traditional site-by-site approach has created a large number of individual stormwater management systems and BMPs that are widely distributed and have become a substantial part of the contemporary urban and suburban landscape.

The problem with the traditional approach is that the facilities are not designed to work as a *system* on a watershed scale. As a watershed is gradually built out, an unplanned system of site-based BMPs can actually increase flooding and channel erosion on a watershed scale, due to the effect of many facilities discharging into a receiving water body in an uncoordinated manner – often causing or aggravating the very problems the individual BMPs were built to prevent.

Stormwater management is most effectively undertaken in the context of a watershed management plan, with lower life-cycle costs to all involved. A watershed management plan is a comprehensive framework for applying management tools in a manner that achieves the water resource goals for the watershed as a whole (CWP, 1998a). Typically, watershed management plans are developed from watershed studies undertaken by one or more municipalities located within the watershed. The watershed approach has emerged over the past decade as the recommended approach for addressing nonpoint source pollution problems, including polluted stormwater runoff. Watershed planning offers the best means to:

- Address cumulative impacts derived from a number of new land development projects;
- Plan for mitigation to address cumulative impacts from existing developments;
- Focus efforts and resources on identified priority water bodies and pollutant sources in a watershed; and
- Achieve noticeable improvements to impaired waters or waters threatened with impairment.

In this context, the term "watershed scale" typically refers to a small local watershed to which the individual site drains (i.e., a few square miles within a single municipality). Ideally, stormwater management should occur on a watershed scale to prevent flow control problems from occurring or reducing the chances that they might become worse.

The watershed approach is built on **three main principles**:

- First, the target watersheds should be those where stormwater impacts pose the greatest risk to human health, ecological resources, desirable uses of the water, or a combination of these issues – typical watersheds where growth and development are occurring.
- Second, parties with a stake in the specific local situation (i.e., stakeholders) should participate in the analysis of problems and the creation of solutions, creating significant "buy in" from those affected.
- Third, the actions undertaken should draw on the full range of methods and tools available, integrating them into a coordinated, multi-organization attack on the problems.

Watershed stormwater design can optimize the number, size and location of BMPs and result in more manageable long-term operation and maintenance of these facilities. Such an approach allows the developer, designer, plan reviewer, owners and the municipality to jointly participate in master planning and installation and operation of a linked and shared system of distributed practices across multiple sites that achieve small watershed-specific objectives, such as flood protection, stream protection and restoration, and water quality.

Furthermore, stormwater systems designed on a watershed basis are more likely to be perceived by local citizens as a multi-functional resource that can contribute to the overall quality of the urban environment. Potential even exists to make the stormwater system a primary component of the civic framework of the community – elements of the public realm that serve to enhance a community's quality of life , such as public spaces, greenways and parks. A more detailed discussion of watershed-scale stormwater management planning is provided in **Appendix 5-B** of this chapter.

5.6 SUMMARY

Taking all of the elements above into consideration, ***the emerging goal of stormwater management is to mimic, as much as possible, the hydrological and water quality processes of natural systems as rain travels from the roof to the stream, through combined application of a series of practices throughout the entire development site and extending to the stream corridor***. The series of BMPs incrementally reduces the volume of stormwater on its way to the stream, thereby reducing the amount of conventional stormwater infrastructure required.

There is no single BMP prescription that can be applied to each kind of development; rather, a combination of interacting practices must be used for full and effective treatment. For a low-density residential Greenfield setting, a combination of BMPs that might be implemented is illustrated in **Table 5.6**. There are many successful examples of BMPs in this context and at different scales. By contrast, **Tables 5.7 and 5.8** outline how the general "roof-to-stream" stormwater approach is adapted for intense industrial operations and urban redevelopment sites, respectively. As can be seen, these development situations require a different combination of BMPs and practices to address the unique design challenges of dense urban environments. The tables are meant to be illustrative of certain situations; other scenarios, such as commercial development, would likely required additional tables.

In summary, a watershed approach for organizing site-based stormwater decisions is generally superior to making site-based decisions in isolation. Communities that adopt the preceding watershed elements not only can maximize the performance of the entire system of BMPs to meet local watershed objectives, but also can maximize other urban functions, reduce total costs, and reduce future maintenance burdens.

Table 5.6. From the Roof to the Stream: BMPs in a Residential Greenfield

BMP	What It Is	What It Replaces	How It Works
Land-Use Planning	Early Site assessment	Doing SWM design after site layout	Map and plan submitted at earliest stage of development review showing environmental, drainage, and soil features
Conservation of Natural Areas	Maximize forest canopy	Mass clearing	Preservation of priority forests and reforestation of turf areas to intercept rainfall
Earthwork Minimization	Conserve soils and contours	Mass grading and soil compaction	Construction practices to conserve soil structure and only disturb a small site footprint
Impervious Cover Minimization	Better (Environmental) Site Design	Large streets, lots and cul-de-sacs	Narrower streets, permeable driveways, clustering lots, and other actions to reduce site IC
Runoff Volume Reduction – Rainwater Harvesting	Utilize rooftop runoff	Direct connected roof leaders	A series of practices to capture, disconnect, store, infiltrate, or harvest rooftop runoff
Runoff Volume Reduction – Vegetated	Front yard bioretention	Positive drainage from rooftop to road	Grading front yard to treat roof, lawn, and driveway runoff using shallow bioretention
	Dry Swales	Curb/gutter and storm drain pipes	Shallow, well-drained bioretention swales located in the street right-of-way
Peak Reduction and Runoff Treatment	Linear Wetlands (Wet Swales)	Large detention ponds	Long, multi-cell, forested wetlands located in the stormwater conveyance system
Aquatic Buffers and Managed Floodplains	Stream buffer management	Unmanaged stream buffers	Active reforestation of buffers and restoration of degraded streams
NOTE: BMPs are applied in a series, although all of the above may not be needed at a given residential site. This "roof-to-stream" approach works best for low- to medium-density residential developments.			

Table 5.7. From the Roof to the Outfall: BMPs in an Industrial Context

BMP Category	What It Is	What It Replaces	How It Works
Pollution Prevention	Drainage mapping	No map	Analysis of the locations and connections of the stormwater and wastewater infrastructure from the site
	Hotspot site investigation	Visual inspection	Systematic assessment of runoff problems and pollution prevention opportunities at the site
	Rooftop management	Uncontrolled rooftop runoff	Use of alternative roof surfaces or coatings to reduce metal runoff, and disconnection of roof runoff for stormwater treatment
	Exterior maintenance practices	Routine plant maintenance	Special practices to reduce discharges during painting, power washing, cleaning, seal coating and sandblasting
	Extending roofs for no exposure	Exposed hotspot operations	Extending covers over susceptible loading/unloading, fueling, outdoor storage, and waste management operations
	Vehicular pollution prevention	Uncontrolled vehicle operations	Pollution prevention practices applied to vehicle repair, washing, fueling, and parking operations
	Outdoor pollution prevention practices	Outdoor materials storage	Prevent rainwater from contact with potential pollutants by covering, secondary containment, or diversion from the storm-drain system
	Waste management practices	Exposed dumpster or waste streams	Improved dumpster location, management, and treatment to prevent contact with rainwater or runoff
	Spill control plan and response	No plan	Develop and text response to spills to the storm drain system, train employees, and have spill control kits available on-site
	Greenscaping	Routine landscape and turf maintenance	Reduce use of pesticides, fertilization, and irrigation in pervious areas, and convert turf to forest cover
	Employee stewardship	Lack of stormwater awareness	Regular ongoing training of employees on stormwater problems and pollution prevention practices
	Site housekeeping and stormwater maintenance	Dirty site and unmaintained infrastructure	Regular sweeping, storm-drain cleanouts, litter pickup, and maintenance of stormwater infrastructure
Runoff Treatment	Stormwater retrofitting	No stormwater treatment	Filtering retrofits to remove pollutants from the most severe hotspot areas
IDDE	Outfall analysis	No monitoring	Monitoring of outfall quality to measure effectiveness
NOTE: While many BMPs are used at each individual industrial site, the exact combination depends on the specific configuration, operations, and footprint of each site.			

Table 5.8. From the Roof to the Street: BMPs in a Redevelopment Context

BMP Category	What It Is	What It Replaces	How It Works
Impervious Cover Minimization	Site design to prevent pollution	Conventional site design	Designing the redevelopment footprint to restore natural area remnants, minimize needless impervious cover, and reduce hotspot potential
Runoff Volume Reduction – Rainwater Harvesting and Vegetated Roofs	Treatment on the roof	Traditional rooftops	Use of green rooftops to reduce runoff generated from roof surfaces
	Rooftop runoff treatment	Directly connected roof leaders	Use of rain tanks, cisterns, and rooftop disconnection to capture, store, and treat runoff
	Runoff treatment in landscaping	Traditional landscaping	Use of foundation planters and bioretention areas to treat runoff from parking lots and rooftops
Soil Conservation and Restoration	Runoff reduction in pervious areas	Impervious areas or compacted soils	Reducing runoff from compacted soils through tilling and compost amendments, and in some cases, removal of unneeded impervious cover
	Increase urban tree canopy	Turf or landscaping	Providing adequate rooting volume to develop mature tree canopy to intercept rainfall
Runoff Reduction – Subsurface	Increase permeability of impervious cover	Hard asphalt or concrete	Use of permeable pavers, porous concrete, and similar products to decrease runoff generation from parking lots and other hard surfaces
Runoff Reduction – Vegetated	Runoff treatment in the street	Sidewalks, curb and gutter, and storm drains	Use of expanded tree pits, dry swales and street bioretention cells to further treat runoff in the street or its right-of-way
Runoff Treatment	Underground treatment	Catch basins and storm-drain pipes	Use of underground sand filters and other practices to treat hotspot runoff quality at the site
Municipal Housekeeping	Street Cleaning	Unswept streets	Targeted street cleaning on priority streets to remove trash and gross solids
Watershed Planning	Off-site stormwater treatment or mitigation	On-site waivers	Stormwater retrofits or restoration projects elsewhere in the watershed to compensate for stormwater requirements that cannot be met on-site
NOTE: BMPs are applied in series, although all of the above may not be needed at a given redevelopment site.			

5.7 REFERENCES

Arendt, R. 1996. Conservation *Design for Subdivisions*. Covelo, CA: Island Press.

Athayde, D. N., P. E. Shelly, E. D. Driscoll, D. Gaboury, and G. Boyd. 1983. *Results of the Nationwide Urban Runoff Program – Vol. 1, Final Report*. EPA WH-554. Washington, DC: EPA

Atlanta Regional Commission (ARC). 2001. *Georgia Stormwater Design Manual,* Volume 2: Technical Handbook. Atlanta, GA.

Bannerman, R., J. Konrad, D. Becker, G. V. Sirnsiman, G. Chesters, J. Goodrich-Mahoney, and B. Abrams. 1979. *The UC Menomonee River Watershed Study – Surface Water Monitoring Data*. EPA-905/4-79-029. U. S. Environmental Protection Agency, Chicago.

Bannerman, R. K. Baum, M. Bohn, P. E. Hughes, and D. A. Graczyk. 1983. *Evaluation of Urban Nonpoint Sources Pollution Management in Milwaukee County, Wisconsin – Vol. 1, Urban Stormwater Characteristics, Constituent Sources, and Management by Street Sweeping.* Chicago, U.S. PB 84-114164. Springfield, VA: NTIS

Bilkovic, D.M., Roggero, M., Hershner, C. H., and Havens, K. H. 2006. "Influence of Land Use on Macrobenthic Communities in Nearshore Estuarine Habitats. *Estuaries and Coasts*, 29(6B), 1185-1195.

Cappiella, K., T. Schueler, and T. Wright. 2005. *Urban Watershed Forestry Manual.* Part 2: Conserving and Planting Trees at Development Sites. USDA Forest Service, Newtown Square, PA.

Center for Watershed Protection (CWP). 1998. *Better Site Design: A Handbook for Changing Development Rules in Your Community.* Ellicott City, MD.

Center for Watershed Protection (CWP). 2003. *Impacts of IC on Aquatic Systems*. Ellicott City, MD.

Center for Watershed Protection (CWP). 2007. *Urban Stormwater Retrofit Practices. Manual 3, Urban Subwatershed Restoration Manual Series*, Ellicott City, MD.

Center for Watershed Protection (CWP) and Virginia Department of Conservation & Recreation (VA DCR). (2007). *Virginia Stormwater Management: Nutrient Design System, Version 1.2.* June 23, 2007.

Center for Watershed Protection (CWP). 2008. *Municipal Pollution Prevention / Good Housekeeping Practices. Manual 9, Urban Subwatershed Restoration Manual Series*. Ellicott City, MD.

Chesapeake Stormwater Network (CSN). 2011. Technical Bulletin No. 5. Version 3.0. *Stormwater Design for Redevelopment Projects in Highly Urban Areas of the Chesapeake Bay Watershed*. Chesapeake Stormwater Network, Baltimore, MD.

Connecticut Department of Environmental Protection (DEP). 1995. *Connecticut Stormwater Quality Planning: A Guide for Municipal Officials and Regional Planners (draft)*. Bureau of Water Management, Planning and Standards Division. Hartford, Connecticut.

Ferguson, B. K. 1991. "The Failure of Detention and the Future of Stormwater Design." *Landscape Architecture* 81(12):76-79.

Ferguson, B. K. 1994. *Stormwater Infiltration.* Boca Raton, FL. CRC Press.

Law N.L., Cappiella, K., Novotney, M.E. 2008. "The need to address both impervious and pervious surfaces in urban watershed and stormwater management." *Journal of Hydrologic Engineering* (accepted).

Legg, A. R. Bannerman and J. Panuska. 1996. Variation in the relation of runoff from residential lawns in Madison, Wisconsin. *USGS Water Resources Investigations Report 96-4194*.

Leopold, L. B. 1968. *Hydrology and Urban Planning – A Guidebook on the Hydrologic Effects of Urban Land Use*. USGS Circular 554. Washington, D.C.: U.S. Geological Survey.

Lichter J. and P. Lindsey. 1994. Soil compaction and site construction: assessment and case studies. *The Landscape Below Ground*. International Society of Arboriculture

Maryland Department of the Environment (MDE). 2000. *Maryland Stormwater Design Manual*. Baltimore, MD.

McCuen, R.H. 1979. "Downstream effects of stormwater management basins." *Journal of Hydraulics Division* 105(11):1343-1356.

McHarg, I. L., and F. R. Steiner. 1998. *To Heal the Earth. Selected Writings of Ian McHarg.* Washington, D.C.: Island Press.

McHarg, I. L., and J. Sutton. 1975. "Ecological Plumbing for the Texas Coastal Plain." *Landscape Architecture* 65:78-89.

Minnesota Pollution Control Agency (MPCA). 2005. *Minnesota Stormwater Manual*. Minneapolis, MN.

National Research Council (NRC). 2008. Water and Science Technology Board, Division of Earth and Life Studies. "Chapter 3 Hydrologic, Geomorphic, and Biological Effects of Urbanization on Watersheds." *Urban Stormwater Management in the United States*. Washington, DC: National Academies Press. 109+. URL: http://www.nap.edu/catalog.php?record_id=12465#toc.

Natural Resources Defense Council (NRDC). 2006. *Rooftops to Rivers. Green Strategies for Controlling Stormwater and Combined Sewer Overflows*. Washington, DC

New York State Department of Environmental Conservation (NYDEC). 2001. *New York State Stormwater Management Design Manual*. Prepared by the Center for Watershed Protection. Albany, NY.

Novotny, V. 1995. *Nonpoint Pollution and Urban Stormwater Management*. Technomic Publishing Company, Inc. Lancaster, Pennsylvania.

Ocean County Soil Conservation District (OCSCD), Schnabel Engineering Associates, Inc. and U.S. Department of Agriculture (USDA) Natural Resources Conservation Service. 2001. *Impact of Soil Disturbance During Construction on Bulk Density and Infiltration in Ocean County, New Jersey*. OCSCD, Forked River, NJ.

Ontario Ministry of the Environment (OME). 2003. *Final Stormwater Management Planning and Design Manual.* Aquafor Beech Ltd. Toronto, Canada

Pennsylvania Association of Conservation Districts, Keystone chapter Soil and Water Conservation Society, Pennsylvania Department of Environmental Protection, and Natural Resources Conservation Service. 1998. *Pennsylvania Handbook of Best Management Practices for Developing Areas,* prepared by CH2MHILL.

Pitt, R. S. Chen, S. Clark and J. Lantrip. 2005. Soil structure effects associated with urbanization and the benefits of soil amendments. World Water and Environmental Resources Congress. Conference Proceedings. American Society of Civil Engineers. Anchorage, AK.

Pitt, R., Maestre, A., and Morquecho, R. 2004. “National Stormwater Quality Database. Version 1.1.” <http://rpitt.eng.ua.edu/Research/ms4/Paper/Mainms4paper.html> (Jan. 28, 2008).

Pitt, R., Chen, S., and Clark, S. 2002. “Compacted Urban Soils Effects on Infiltration and Bioretention Stormwater Control Designs.” *Proceedings of the Ninth International Conference on Urban Drainage: Global Solutions for Urban Drainage*, American Society of Civil Engineers, Reston, VA.

Pitt, R. J. Lantrip and R. Harrison. 1999. Infiltration through disturbed urban soils and compost-amended soil effects on runoff quality and quantity. Research Report EPA/600/R-00/016. Office of Research and Development. U.S. EPA. Washington, D.C.

Prince George’s County, Maryland. 2000. *Low-Impact Development Design Strategies*. EPA 841-B-00-003. Location: EPA.

Robbins, P., and Birkenholtz, T. 2003. "Turfgrass revolution: measuring the expansion of the American lawn." *Land Use Policy*, 20, 181-194.

Schueler, T. 1987. *Controlling Urban Runoff: a Practical Manual for Planning and Designing Urban Best Management Practices*. Metropolitan Washington Council of Governments. Washington, DC.

Schueler, T.R., Holland, H.K. 2000. “The Compaction of Urban Soils.” *The Practice of Watershed Protection*, Center for Watershed Protection, Ellicott City, MD, 210-214.

Schueler, T. 2001a. “The Compaction of Urban Soils.” *Watershed Protection Techniques*. 3(2): 661-665.

Schueler, T. 2001b. “Can Urban Soil Compaction Be Reversed?” *Watershed Protection Techniques.* 3(2): 666-669.

Shuster, W.D., Bonta, J., Thurston, H., Warnemuende, E., and Smith, D. R. 2005. “Impacts of Impervious Surface on Watershed Hydrology: A Review.” *Urban Water Journal,* 2(4), 263-275.

Traver, R. G., and R. A. Chadderton. 1992. “Accumulation Effects of Stormwater Management Detention Basins.” *Hydraulic Engineering: Saving a Threatened Resource – In Search of Solutions*. Baltimore, MD: American Society of Civil Engineers.

United States Environmental Protection Agency (USEPA). 1983. Results of the Nationwide Urban Runoff Program. Water Planning Division. PB84-185552. Washington, D.C.

USEPA. 1998. *Federal Register Proposed Rules* 63(6): 1536-1643.

USEPA. 1999. *Economic Analysis of the Final Phase II Storm Water Rule.* EPA Doc. 833-R-99-002, Prepared by SAIC: Reston, VA.

USEPA. 2005a. *National Management Measures to Control Nonpoint Source Pollution from Urban Areas.* Washington, D.C.: U.S. Government Printing Office.

US EPA. 2005b. *Using Smart Growth Techniques as Stormwater Best Management Practices*. EPA-231-B-05-002. Smart Growth Team. Office of Water. Washington, D.C.

U.S. EPA. 2006. *Protecting Water Resources with Higher Density Development*. EPA-231-R-06-001. Office of Water. Washington, D.C.

Vermont Department of Environmental Conservation (VTDEC). 2002. The Vermont Stormwater Management Manual. Vermont Agency of Natural Resources.

Walsh, C.J. 2004. “Protection of In-Stream Biota from Urban Impacts: Minimize Catchment Imperviousness or Improve Drainage Design?” *Marine and Freshwater Research*, 55(3), 317-326.

Wang, L., J. Lyons, P. Rasmussen, P. Simons, T. Wiley, and P. Stewart. 2003. “Watershed, reach, and riparian influences on stream fish assemblages in the Northern Lakes and Forest

Ecoregion." *Canadian Journal of Fisheries and Aquatic Science* 60:491-505.